Project-based Cooperative Learning to Enhance Competence while Teaching Engineering Modules

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Abstract— **This paper focuses on teaching control systems to engineering students not only by way of the traditional lecture deliveries, but also by implementing several student-focused problems based self-directed learning projects as well as presentations from students. Engineering field constantly evolves and thus teaching a module to engineering students should involve current state-of-the-art research trends in the lectures. In addition, the tutor should also motivate students to have the current research developments incorporated within the student's self-learning projects. The work presented in this paper revolves around three mini-projects, each project on a different aspect of control engineering and to be completed within two weeks each. The aim of these problem based self-directed learning mini-projects is to get acquainted with the practical aspects of the theoretical learning that has been undertaken within the lectures, something that UK Standard for Professional Engineering Competence (UK-SPEC) focuses on. After completion of the mini-project, the students present their work/discuss results etc. as a power-point presentation lasting 15 minutes, and answer queries from peers (compulsory) and tutor, thus promoting life-long learning along with class participation and peer assessment. The student is also given verbal feedback after each of these project presentations, thereby encouraging improvements in the subsequent presentations taking place after two weeks. The purpose of these projects is to keep alight with the practical aspects of the current professional practices in industry, in the area of engineering, while also building a strong foundation through the self-learning model, thereby promoting deep learning via a blended approach. A questionnaire is also presented in the results and discussion section, which suggests that inclusion of a blended approach has improved the student's reading beyond the course requirements, has encouraged them towards deeper learning, and also improved both their theoretical as well practical aspects in engineering education.**

***Index Terms*— Control engineering, self-learning, mini-projects, deep learning, life-long learning.**

I. Introduction

It is quoted by George Carlin "Don't just teach your children to read. Teach them to question what they read. Teach them to question everything". This aspect is true for any teaching, and especially true when teaching engineering (Goodhew 2010). Teaching and learning in engineering should include lecture/tutorial, problem-based, project-based, student-centered as well as co-operative learning[1] along with simulation and E-learning aspects (Goodhew 2010). As per the studies undertaken by Mayer in (Mayer 2013), it has been suggested that students who learn science and engineering concepts experience a higher workload because this knowledge has a richer, more complex structure (Perrenet, Bouhuijs et al. 2000). The present studies suggest that it is possible to have transition to a greater percentage of engineering education into Problem Based Learning (PBL) - based laboratories, and that this method has the potential to transform learning. PBL is now a widespread teaching method in disciplines (Du, de Graaff et al. 2009) where students must learn to apply knowledge, not just acquire it (Brodeur, Young et al. 2002). This is especially true for design-build kind of teaching learning education; which the module Control System engineering is all about. This module has working models of controlling a DC motor, an inverted pendulum as well as vertical take-off and landing system, as part of student projects (cf. Section II B). Thus, one should shift from teaching to learning as a vision rooted in practical experiences (Woods 1994), while teaching Control System engineering. This involves introducing new ideas and determining whether and how these can be implemented in practice (Ferlazzo 2013), thereby also motivating students to ask more questions.

The control systems module was previously taught with major emphasis on lecturing, and had only one project that related practice to theory. This resulted in students of Control engineering having to encounter difficulties assimilating the theoretical concepts explained in the lectures with the practicalities, as discussed in (Méndez, Lorenzo et al. 2006). This is prominently also due to the fact that before affording elementary control systems design, it is necessary to explain many mathematical concepts. The Institute of Electrical and Electronics Engineers (IEEE)[2] Control System Society identified the gaps between control system education and industry expectations of entry-level control engineers. For e.g.,

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[1] It refers to the benefits to students of learning in collaboration with other students.

[2] The IEEE is the world's largest professional association for the advancement of technology. For more information, please see https://www.ieee.org/index.html

industry practitioners indicated that students need to be more familiar with software packages used in the industry, and need to have more industry-focused control design skills (Arkadiy Turevskiy 2013), such as having the expertise in MATLAB[3] and LABVIEW[4]. A survey of the UK community, with perspectives from leading academics such as Reading, Imperial, Sheffield, Leicester, Newcastle, Manchester and Glasgow Caledonian as well as industry, has been carried out specifically focusing on a typical curriculum for teaching control engineering (Rossiter, Giaouris et al. 2008). The general consensus of this research is that control software such as MATLAB/Simulink[5] is widely used in industry and it effectively ensures that the students are immediately employable to fulfil the expectations of the industry. In addition, this research suggests that Control engineering is easier to teach when people have physical experience of the systems (not just software). Thus, it was recommended to have a split of about 30:70 practical assessments to examinations as appropriate. Similar views in terms of blended learning in control engineering were also suggested in (Rossiter 2006). A mixed-mode approach has also been successfully adopted at several of the institutions examined in (Mills, Treagust 2003), with some traditionally taught courses, particularly in the early years, mixed with some project-based components and with the project based components increasing in extent, complexity and student autonomy in later years of the program, appears to be the best way to satisfy industry needs, without sacrificing knowledge of engineering fundamentals. It was therefore planned to have a combination of lectures[6] and assignments (which also focuses on industry-focussed software packages/real-time simulations, modelling and mathematical foundation based exercises) to cover the theoretical aspects, and later to have practical mini-projects to deal with the hands-on understanding of Control engineering.

The remainder of the paper is organized into three sections. Section II describes the methodology of how the approach has been implemented, while also observing UK Standard for Professional Engineering Competence (UK-SPEC) guidelines. Section III discusses the benefits and challenges of the implemented approach as well as the evaluation methodology. Section IV concludes the paper.

II. Methodology of Implementation

The method presented in this paper revolves around several problem based self-directed learning projects as well as student presentations and the tutor's lecture deliveries while teaching control systems engineering. This module on Control systems engineering forms part of year 2 studies within the program of BEng/MEng Mechatronics, BEng/MEng Robotics and BEng/MEng Electronics taught at a UK Higher Education Institute (HEI). Therefore, the module is expected to adhere to the general UK-SPEC (cf. Section II-D) guidelines. On completion of this module, the successful student will have knowledge and understanding of the fundamentals of classical control systems and their design methods as well as be aware of advanced control algorithms. The successful student will also have developed the skills to develop a system model based on information about a typical application, as well as be able to apply the advanced techniques used to design and analyze the performance of practical feedback control systems in both time and frequency domain; and also be familiar with common computer aided control design packages such as MATLAB/Simulink and LabVIEW in modelling, analyzing and prototyping control systems.

Engineering field constantly evolves and thus it is intended to involve current state-of-the-art research trends in lectures and also motivate students to have current research developments incorporated within their self-learning projects. The module was taught over 12 weeks, each week comprising 6 hours of contact time between the tutor and the student, with no end of module assessment, but a continuous assessment/feedback by way of assignments and project presentations. Thus the task involved

- Lecture deliveries
- Problem based self-directed learning projects

A. *Laying the foundations*

The plan was to undertake lecture sessions in the first six weeks of teaching this module. The focus was on building the foundations of this module as well as motivate students to think in this particular area of engineering. This includes teaching the fundamental mathematics related to Control engineering which is vital for future engineers. To have the lecture sessions interesting and motivating, an end of week assignment was given each week, followed by an e-quiz in Week 3 and Week 6. The assignments involved, as discussed in Section I, the theoretical foundations and software based simulations/experiments etc. and was a part of the summative assessment. The online e-quiz was based on Socrative (Méndez, Slisko 2013). However, the e-quiz was not summatively assessed, as it was intended to have students to undergo learning with fun (Higley, Marianno 2001). Thus, after a question was answered within the e-quiz assessment, each student's name as well as the answer (s)he has given was displayed on the projector screen, thus the student was expected to answer with fun (courtesy no marking) but also had to be serious (courtesy projector displaying everyone's answer). Thus the purpose here was to have a two-way communication for productive teaching/learning in the first few weeks of this module, when the students and the tutor are not familiar with each another.

Typically, lectures should be able to identify prior knowledge of the student, construct the knowledge base from thereon, the students present what they have learned from the knowledge construction, and lastly debriefing by the lecturer (Tan 2013). Thus, before beginning a lecture session, the tutor

[3] MATLAB, developed by MathWorks, is a multi-paradigm high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation.

[4] LabVIEW itself is a software development environment that contains numerous components, several of which are required for any type of test, measurement, or control application.

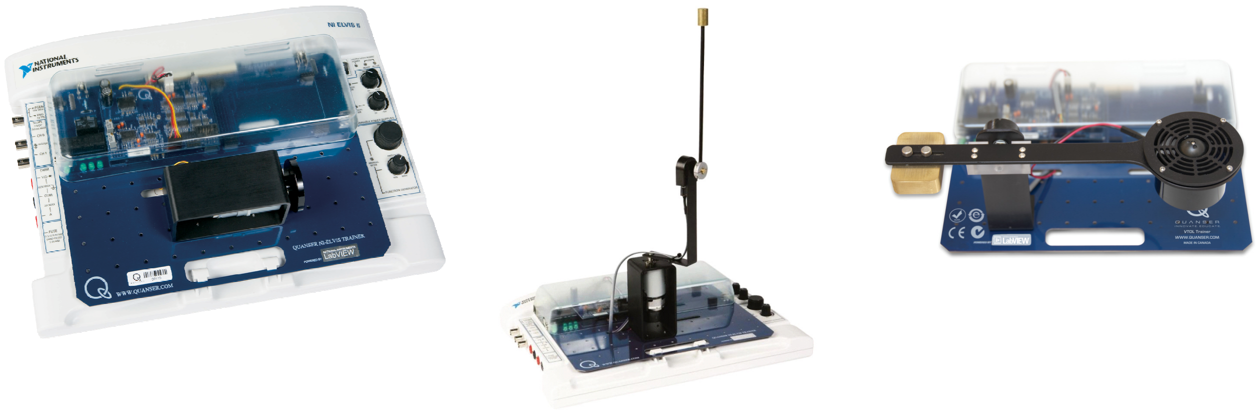
[5] Simulink, is an add-on product to MATLAB, that provides an interactive, graphical environment for modeling, simulation, and analyzing of dynamical control systems.

[6] "Lectures are the best way to get students to think" (Gibbs 1981)

usually spent the first few minutes conversing what was discussed in the previous lecture. This also acted as an ice breaker. Here, the tutor requested students, one at a time randomly (and not necessarily everyone), to let everybody else know of what was discussed/taught in the previous class. This essentially formed a summary of the discussion from the previous session. Additionally, when a student let his views, the tutor was able to correct, if needed. This was also a kind of feedback, and the tutor was able to figure out an individual student's needs in terms of their technical understanding of the subject. This helped the tutor spend more time with particular student(s) in need. The tutor would spend this "more" time with the students during several of the in-class problem solving micro time-breaks that s(he) offered during the session.

B. Building up on the foundations

The distinction between deep and surface learning is in the depth of involvement, commitment, interaction and application (Entwistle 1990) as cited in (Raaheim, Wankowski 1981). However, recent studies in (Haggis 2009a, Haggis 2009b) suggest that there are many aspects of learning, it is still not well understood and requires more investigation. One should therefore, without getting into complexities, seek active engagement with the subject matter, seek real meaning and interests through interactive lecture sessions. Thus, once the foundation was built in these six weeks through lecture sessions and assignments, then the three mini-projects were given to the students, each mini-project in a group of two on a different aspect of control engineering and to be completed within two weeks each, but this started from week 7 onwards. The aim of these mini-projects was to have the student get acquainted with the practical aspects of the theoretical learning that was undertaken within the first six weeks. *Week 1 to 6 thus focused on teaching through lectures and assignments*, and after sufficient theoretical grounding was achieved, *week 7 to 12 focused on teaching through the 3 projects and assignments*. The purpose of the mini-projects, as discussed in Section I, was to enable students to apply the knowledge, not just acquire it. Thus, one needs to combine lectures and practical sessions to teach the "Messiness" of Engineering (Gibbs 1981).



(a) DC motor (b) Rotary pendulum (c) Vertical take-off and landing system

Figure 1: QNET board with NI ELVIS bench top workstation for three mini-projects

The students were given a handout outlining the task and the experiments that were expected to be carried out within a particular mini-project. The three mini-projects relate to DC motor control, inverted pendulum and a vertical take-off and lading system (cf. Figure 1). Each project took approximately 3-4 hours to complete, which included comprehensive experiments, writing a report and also presenting these in a seminar that lasted for about 15 minutes. The mini-projects were to be completed in the student's own time but within the stipulated 2-week time duration. The student might have questions during the course of the project, however, the tutor would ask them some indirect questions, which would in a way try to bring out the answer from their end, thus promoting deep learning. The tutor would also encourage the students to think more carefully about the given task or project, and thus boost them towards deeper life-long learning (Sellers, Roberts et al. 2007), which would thus develop their criticality.

The students presented their work/discussed results etc. as a power-point presentation, and answered queries from peers and tutor. Each group of peer student was expected to ask at least one question to the presenter group of students. This promoted class participation and also deep learning, as the student himself had to be thorough in the subject, before asking a question (peer assessment for peer improvement). This approach is backed by results of a similar study in (Tan 2013), which suggests that student participation in the teaching learning activities is essential to promote deep learning. Each of the project had several practical applications, with research being carried out in industries and research institutes, be it the design and development of DC motors or advanced control theory to control a pendulum in an inverted position, or smooth control of a vertical take-off and landing system. Thus, the students were expected to have a know-how of the advancements that are currently in these areas, through a background research, before they present their work in front of peers and the tutor.

C. Assessment

Assessments should be authentic, transparent and designed such that the scope of plagiarism is almost not possible. Only having an end of term assessment approach (like a 3-hour written exam) cannot be recommended, rather the purpose of assessment should be a thorough continuous assessment. The assessment scheme for this module therefore focused on coursework/assignment, which was required to be submitted individually by a student; and 3 mini-projects, which was required to be submitted by students in a group of two. As mentioned in the previous section, the assignments were to be submitted in the first 8 weeks or so, while the mini-projects were to be submitted by the end of week 12 of the module.

The assignments, in addition to theoretical writing, also included writing codes in software packages for simulation based experiments that relate to the real-world aspects of control engineering, thereby developing the practical knowledge base of the student.

Regarding the mini-projects, each student was expected to perform the experiment within the project, complete a pre-defined laboratory report and give a presentation of the work carried out. A series of questions were posed by students as well as the tutor, listening to the student's presentation and the answers/defense by the student's presenting their work. Each student was assessed based on the report, and the depth of the raised question as well as how each student responded to the questions from peers and the tutor at the time of presentation. The students were also asked to write feedback/comments on other student's (and their own) presentation using the module assessment criteria. The students were also given feedback after each of these project presentations, thereby encouraging improvements in the subsequent presentations taking place after two weeks. Thus, the teaching here involved each student as part of the whole development. The purpose of these mini-projects was to keep alight with the practical aspects of the current industry practices in the area of engineering study while also building a strong foundation through the self-learning model, thereby promoting deep learning (Raaheim, Wankowski 1981, Arkadiy Turevskiy 2013). This is evident when students visit industries, and seem to easily correlate what was studied in the module and what practically exists in an automation industry.

D. *Observing UK-SPEC guidelines*

The UK Standard for Professional Engineering Competence (UK-SPEC) describes competence as "The formation process through which engineering professionals become competent generally involves a combination of formal education and further training and experience (generally known as professional development)" (UK-SPEC). The mini-projects are practical demonstration kind of works while the assignments are more theoretical or software/computer based. Thus, the practice project was intended to enable the student become competent, by way of lectures as formal education, and through training/experience obtained through problem based self-directed learning projects which were problem-based and student-centered so that the student's learning closely revolved around the current professional practice in the field.

The UK Professional Standards Framework for teaching and supporting learning in higher education in (Ihr 2011) demonstrated a broad understanding of effective approaches to teaching and learning support as key contributions to high quality student learning. The project was intended to engage across all the five areas of activity, to incorporate an understanding across all aspects of core knowledge, have a commitment to all the professional values for successful engagement in appropriate teaching practice related to the areas of activity, as well as a successful incorporation of subject and pedagogic research within the above activities, as part of an integrated approach to academic practice, for a successful engagement in continuing professional development in relation to teaching, learning, assessment and, where appropriate, related professional practices.

E. *Evaluating the methodology*

Evaluation is either about proving something is working or needed, or improving practice or a project (Rogers, Smith 2006). The first relates to our accountability towards the people we are working with, and the second relates to a desire to do our work, as teachers, to do things better. Both of these aid to enhance our practice. Several approaches to evaluation have been discussed in (Barrett, Moore 2010). Taking clue from this, to evaluate the implemented methodology, the below mentioned tasks were carried out post completion of teaching this module:

1) Teacher's as well as external examiner's opinions about the effectiveness of the implemented project in teaching control engineering. The objective was to find answers to whether the approach has met/exceeded the learning outcomes as by way of introducing a blended approach of theory and practice based projects to teach control systems engineering. In the informal discussion with the examiners regarding the approaches undertaken, it was observed that a blended approach has potentially led the students to have a deeper understanding of implementing the theoretic knowledge and put it into practice.

2) A written questionnaire as well as a personal informally structured interview with students was carried out to create a dataset for the evaluation of the learning outcomes. This has resulted in information as shown in Figure 2. A few open-ended questions such as "What do you think can be improved in this course?" and "What do you like most about this course?" were also put up verbally. The purpose here was to bring out the message, if it existed, whether blended learning had been appropriate for this module or not, in terms of

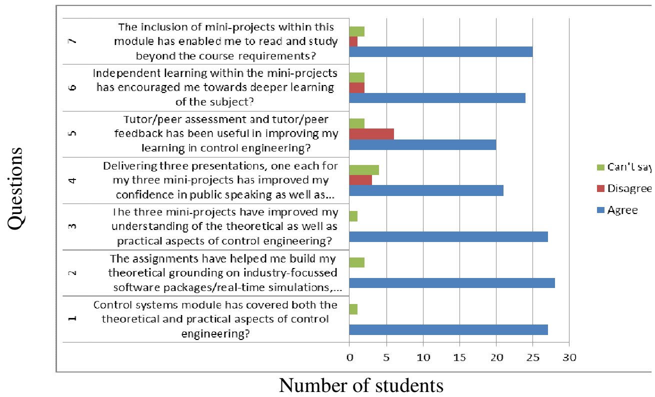


Figure 2: Questionnaire and student response

student learning and experience. From Figure 2 it can be concluded that the inclusion of a blended approach has improved the student's reading beyond the course requirements, has encouraged them towards deeper learning, has improved their public speaking confidence, and also improved both their theoretical as well as practical aspects of learning the particular module. Industry's opinions about the change in teaching and assessment strategies implemented in this module were also sought. Personnel from the industry were shown the work that was carried out by the students as a part of their mini-projects.

3) The best way to teach control engineering has been reviewed by different universities (Rossiter, Giaouris et al. 2008), and self-evaluated/critically evaluated by us as well thereby leading us towards having a personal style of teaching control engineering. Thus, this resulted in having a combination of lectures, assignments and mini-projects, to bring out the best from each of these approaches, for the benefit of students learning a diverse module as control engineering, which not only involved theory but also put theory to practice.

Thus, the purpose of this evaluation approach was participatory as well as inclusive, in that not only it engaged all stakeholders, but it also involved them in collaborating in the evaluation activities and in sharing the lessons learnt from evaluation, as suggested in (Moore 2011).

III. Benefits and Challenges of the Methodology

As discussed in Section II, when we as tutors do not answer to queries directly, but rather try to bring the answer from the student's end, some students did find this approach difficult to digest. However, as the module progressed, the students became aware that this process is in fact in their best interest (Sellers, Roberts et al. 2007). The understanding that the student gets from this kind of self-directed learning experience (with tutor acting as a facilitator rather than a traditional instructor, as in the Travelling theory presented in (Fox 1983)) remains for a lifetime even long after the student would complete the module. An understanding from the proverb "Give a man a fish and he will eat for a day. Teach a man to fish and he will eat for a lifetime" suggests that one should guide the student towards how to learn rather than precisely teach him/her what (s)he is expecting. However, this needs lots of effort from both the tutor and the student. The role of an instructor is thus to be able to introduce topics in an interesting way but also have the deliverables clear from day 1.

Secondly, the students also found the large number of assignments and mini-projects that form a part of summative assessment as substantial, and wanted to decrease this number, however, since there was no end of term assessment for this module, a substantial chunk of assignments was required for good theoretical grounding, and the mini-projects assisted in sound practical knowledge (a UK-SPEC requisite to achieve competence in a particular area).

Thirdly, there could be conflicts if students were to write feedback and/or assess the peer students. To avoid these encounters, the tutor obtained the written feedback from students but would not display it as it is to them. Rather, the tutor would append these with his/her own feedback, and discuss a complete detailed feedback with the individual student, without obviously not mentioning specifically who had written a particular feedback for whom. This eluded resentment for a negative feedback that was given by an X student for a Y student. This approach also introduced reliability and transparency in assessment. From the student's perspective, it enhanced communication of ideas, encouraged independence, collaboration as well as co-operation and also improved presentation skills while at the same time the students also gained from practical project experience and an opportunity for authentic skill development.

IV. Conclusion

Based on what is expected from the UK-SPEC (cf. section II-D), what has been the outcome of the research into the considerations to have while teaching control systems (cf. section I) as well as our own research, we can clearly see the need to have an amalgamation of theoretical and practical methods and means while teaching engineering, especially so diverse and interdisciplinary as Control engineering. In agreement with the views as discussed in (Goodhew 2010, Rossiter, Giaouris et al. 2008, Rossiter 2006), in order to ensure that the students are immediately employable, it is imperative that they are equipped not only with the theoretical knowledge but should also have knowledge of the software as well as practical applications of the same. This can be ensured by encouraging students towards deeper life-long learning, and motivating them towards reading beyond the course requirements. This is what this paper intended to achieve by integrating lectures, assignment and mini-projects i.e., equip students with life-long learning in the area of control engineering. And this happens when the student has the necessary practical exposure in addition to the theoretic knowledge, while journeying through a particular module.

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